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13. ABSTRACT (Maximum 200 words)

The PI and his students have developed novel algorithms for boundary computation, model simplification, fast display and interference detection. These include use of exact arithmetic for robust and accurate boundary computation, development of an interactive solid modeler using parallel algorithms and implementations, simplification with guaranteed error bounds for large polygonal models, occlusion culling, interactive display of large spline models and efficient collision detection between general polygonal models.

The resulting algorithms and systems have been applied to a number of applications and the technology has been transferred to a number of research and DOD labs as well as commercial vendors.

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PROJECT TITLE: Modeling and Interactive Walkthrough of Large CAD Models

Research Agreement: DAAH04-96-1-0257

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1. Technical Objectives and Motivation

We are addressing some fundamental research issues in modeling, display and simulation for computer-aided design and virtual environments. Our emphasis is to develop better algorithms and software systems and to demonstrate their applications. The set of problems include:

A. Robust and interactive algorithms for modeling physical objects using boolean operations.
B. Hierarchical and multiresolution representations of models for fast display.
C. Develop a robust system to compute boundary representation of solids defined using boolean combination of sculptured models and integrate it with the BRL-CAD solid modeling system.
D. Interactive display of large scale polygonal, sculptured and solid models on current graphics systems.

2. Approach

We are utilizing number of techniques from algebraic geometry, approximation theory, computational geometry, numerical analysis, computer-aided geometric design and computer graphics to investigate the underlying mathematical concepts and to develop more efficient and robust geometric algorithms. This includes algorithms and systems for computing boundary representations of constructive solid geometry models composed of spline primitives and their boolean combinations. In particular, we propose to compute accurate spline representations of the intersection curve with guaranteed error bounds and make use of a number of algorithms from computational geometry and discrete mathematics to represent the topologies of the given solids. The resulting system is being integrated with BRL-CAD and being applied to computing an accurate boundary representation of a Bradley fighting vehicle.

We are also developing improved algorithms for polygon and surface triangulation, simplification, visibility and hierarchical representations for developing interactive systems for displaying large datasets. Eventually, we will interface these systems with the immersive hardware and apply them for interactive walkthrough of the fighting vehicle.

3. Significant Accomplishments

The PI and his students have developed novel algorithms for boundary computation, model simplification, fast display and interference detection. These include use of exact arithmetic for robust and accurate boundary computation, development of an interactive solid modeler using parallel algorithms and implementations, simplification with guaranteed error bounds for large polygonal models, occlusion culling, interactive display of large spline models and efficient collision detection between general polygonal models.

The resulting algorithms and systems have been applied to a number of applications and the technology has been transferred to a number of research and DOD labs as well as commercial vendors.

4. Cooperation with and Technology Transfer to Army Laboratories and Other Organizations

A: Army Research Labs, Aberdeen, MD:} The PI and his graduate students are integrating our solid modeler, BOOLE, with the BRL-CAD solid modeling system developed by researchers at Army Research Labs, Aberdeen. BRL-CAD is primarily used for {\em vulnerability analysis} at ARL and it has more than 1600 users worldwide. BOOLE will be used for performing boolean operations on curved surfaces.

B: I-COLLIDE, RAPID, V-COLLIDE, PQp Collision Detection System:} More than $4200 $ users all over the world have copied the source code of our different collision detection systems.
Some of the prominent users are at Sandia National Labs, Lockheed Martin, Ford Motor Company, Division, Engineering Animation, Army Research Labs, Evans and Sutherland, etc. The system has also been licensed to Mechanical Dynamics Inc., Intel, Kawasaki, Amada, Simlog and Division Inc.

C: White Sands Missile Range, NM:} The algorithms and systems for collision detection have been incorporated into a {\em missile distance display scenario}. The purpose of the scenario is to produce a visual display of the results of an engagement between a missile and a target. The main objective is to provide information in sufficient detail to permit missile system performance evaluation.

D: Lockheed-Martin, Electric Boat and Newport News Shipbuilding:} The PI and his students have been actively collaborating with researchers at these organizations and other universities for more than two years as part of ARPA's project on {\em Simulation-based Design}. In particular, the software technology for model generation, simplification and fast display is being used for interactive walkthrough of submarines and ship-models.

E: Air Force's Philip Laboratory, NM:} The solid modeling and fast rendering systems, developed at UNC, are used for

model generation and fast display of satellite systems.

5. **Publications in Refereed Journals and Conference Proceedings**

1. J. Keyser, T. Culver, D. Manocha and S. Krishnan (2000) "Efficient and Exact Manipulation of Algebraic Points and Curves", Computer-Aided Design, Special issue on Robustness, to appear.

2. S. Krishnan and D. Manocha (2000) "Hidden surface removal algorithms for sculptured models", Graphical Models and Image Processing, 24 pages, to appear.

3. A. Gregory, A. State, M. C. Lin, D. Manocha and M. Livingston, "Interactive Surface Decomposition for Polyhedral Morphing", Visual Computer, vol. 15, pp. 453-470, 1999.

4. M. Gopi and D. Manocha (1999) "Simplifying Spline Models", Computational Geometry: Theory and Applications, vol. 14, pp. 67-90, 1999.

5. K. Hoff, T. Culver, J. Keyser, M. Lin and D. Manocha, "Fast Computation of Generalized Voronoi Diagrams using Graphics Hardware", Proceedings of ACM SIGGRAPH, 1999.

6. J. Keyser, S. Krishnan and D. Manocha (1999) "Efficient and Accurate B-rep Generation of Low Degree Sculptured Solids Using Exact Arithmetic:I - Representations", Computer-Aided Geometric Design, 23 pages.

7. J. Keyser, S. Krishnan and D. Manocha (1999) "Efficient and Accurate B-rep Generation of Low Degree Sculptured Solids Using Exact Arithmetic:II - Computation", Computer-Aided Geometric Design, 25 pages.

8. S. Krishnan, D. Manocha, M. Gopi, T. Culver and J. Keyesr (1999) "BOOLE: A Boundary Evaluation System for Boolean Combinations of Sculptured Solids", International Journal on Computational Geometry and Applications, to appear, 31 pages.

9. A. Wilson, E. Larsen, D. Manocha and M. Lin, "Partitioning and Handling Massive Models for Interactive Collision Detection", Computer Graphics Forum, 1999.

10. S. Kumar, D. Manocha, W. Garrett and M. Lin (1999) "Hierarchical Backface Computation" Computer and Graphics, Special Issue on Visibility, 1999.

11. A. Wallack and D. Manocha (1998) "Robust Algorithms for Object Localization", International Journal on Computer Vision, vol. 27, no. 3, pp. 243-262.

12. S. Krishnan, M. Gopi, M. Lin, D. Manocha and A. Pattekar, "Rapid and Accurate Contact Determination between Spline Models using ShellTrees", Computer Graphics Forum, 1998.

13. C. Pisula, K. Hoff, M. Lin and D. Manocha, "Randomized Path Planning for a Rigid Body based on Hardware Accelerated Voronoi Sampling", Proc. of 4th International Workshop on Algorithmic Foundations of Robotics, 18 pages, 2000.

14. K. Hoff, T. Culver, J. Keyser, M. Lin and D. Manocha, "Interactive Motion Planning using Hardware Accelerated Computation of Generalized Voronoi

Diagrams", Proc. of IEEE International Conference on Robotics and Automation, 2000, to appear.

15. E. Larsen, S. Gottschalk, M. Lin and D. Manocha, "Fast Distance Queries using Rectangular Swept Sphere Volumes", Proc. of IEEE International Conference on Robotics and Automation, 2000, to appear.

16. D. Aliaga, J. Cohen, A. Wilson, E. Baker, H. Zhang, C. Erikson, K. Hoff, T. Hudson, W. Stuerzlinger, R. Bastos, M. Whitton, F. Brooks and D. Manocha, "A Framework for the Real-Time Walkthrough of Massive Models", Proc. of ACM Symposium on Interactive 3D Graphics, 1999.

17. C. Erikson and D. Manocha, "GAPS: General and Automatic Polygon Simplification", Proc. of ACM Symposium on Interactive 3D Graphics, 1999.

18. T. Culver, J. Keyser and D. Manocha, "Accurate Computation of Medial Axis of a Polygon, Proc. of ACM Symposium on Solid Modeling, 1999.

19. A. Wilson, D. Manocha and M. Lin, "Representation and Interactive Manipulation of Massive CAD Datasets", Proc. of Workshop on Integrated Spatial Databases: Digital Images and GIS, 1999, to appear.

20. J. Keyser, T. Culver, S. Krishnan and D. Manocha, "MAPC: A library for Efficient and Exact Manipulation of Algebraic Points and Curves", Proc. of ACM Symposium on Computational Geometry, 1999.

21. M. Gopi and D. Manocha, "A unified approach for simplifying polygonal and spline models", Proc. of IEEE Visualization'98, pp. 271-278, 1998.

6. Awards and Honors (if any, omit this section if none)

A: The P.I. was awarded Hettleman Award at UNC Chapel Hill.

B: The paper titled "Partitioning and Handling Massive Models for Interactive Collision Detection", by the PI and collaborators received the best student
paper and second best overall paper award at Eurographics, 1999.

7. **Papers or reports in non-refereed publications**

8. Books or book chapters published

9. Patent/Inventions filed or granted

10. Number of graduate and undergraduate students supported by gender and by minority group

T. Culver (Ph.D. student), male

C. Erikson (Ph.D. student), male

K. Hoff (Ph.D. student), male

J. Keyser (Ph.D. student), male

A. Wilson (Ph.D. student), male

11. Number of MS and Ph.D. degrees awarded to students working through the grant and their current employment status and employers

1 Jonatham Cohen (Ph.D. December '98). Assistant Professor at Johns Hopkins Univ.

2 Eric Larsen (M.S. Spring'99). Working at Sony.

3 Amol Pattekar (M.S. Spring'98). Working at Yahoo Inc.

4 Hansong Zhang (Ph.D. Fall '98). Working at Intrinsic Inc.

5 Carl Erikson (Ph.D. February '00). Member of Technical Staff, BOPS Inc.

6 John Keyser (Ph.D. June'00). Assistant Professor at Texas A & M Univ.

12. **Nonexpendable instrumentation purchased; value thereof**

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